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MADRE PERFORMANCE

PART 3 - OBSERVATIONS OF FEBRUARY 12, 1962

[UNCLASSIFIED TITLE]

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G.A. Skaggs, and E.N. Zettle

Radar Techniques Branch
Radar Division

August 30, 1963

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

Previous Reports in This Series

NRL Report 5862, "Madre Performance, Part 1 – Observations of January 18 and 25, 1962" (Secret Report, Unclassified Title), F.M. Gager, W.C. Headrick, G.A. Morgan, F.H. Utley, and E.N. Zettle, Dec. 1962.

NRL Report 5898, Madre Performance, Part 2 – Observations of February 8, 1962" (Secret Report, Unclassified Title), F.M. Gager, W.C. Headrick, G.A. Morgan, D.C. Rohlfs, C.B. Tesauro, and E.N. Zettle, Feb. 1963.

SECURITY

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ABSTRACT
[Secret]

Initial evaluation work on operation of the Madre radar against aircraft targets over the North Atlantic Ocean was reported in Parts 1 and 2 of this series. This report continues with further observations of targets of opportunity within the slant range block 1350 to 1800 nautical miles. Propagation conditions were fair to good. The Madre radar was operated on 16.16 Mc with 100 kw average power applied to the broadside array sighting on an azimuth of 71 degrees. Ten apparent time vs range plots of aircraft are analyzed against position data obtained from the FAA and the Canadian Department of Transport, and again the Madre data are identified with specific flights but often without discrimination between several flights. Finer azimuth discrimination could be installed in the present equipment (beam splitting techniques) but is not believed necessary at present in the evaluation of the radar capabilities. (S)

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

NRL Problem R02-23
Project RF 001-02-41-4007
MIPR (30-602) 63-2928, 29, 95

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VERY-LONG-RANGE, OVER-THE-HORIZON DETECTION OF AIRCRAFT WITH THE MADRE RADAR

PART 3 - OBSERVATIONS OF FEBRUARY 12, 1962
[Secret Title]

INTRODUCTION

NRL Reports 5862 and 5898, Parts 1 and 2 of this series, contain the initial evaluation work to date on the title subject. NRL Report 5903 is a description of the high-power extension to the original low-power Madre. The low-power research radar Madre was for the most part constructed by the General Electric Company (Syracuse, N.Y.) under NRL specifications; the high-power extension to this radar was constructed by RCA (Moorestown, N.J.) also under NRL specifications. In addition to the transmitting equipment, RCA provided an air-turbine-drive, air-bearing memory drum to replace the original General Electric unit as part of the received signal processing.

This report contains data obtained initially from targets of opportunity in the trans-atlantic air traffic lanes between the east coast of the United States and Europe. All the targets of opportunity were incoming flights since the data were obtained at a time of day when incoming flights predominate. The radar was operated on 16.16 Mc with 100 kw average power applied to the Madre broadside array sighting on the azimuth noted (71 degrees). The targets themselves were randomly chosen from those visible on the radar screen.

The targets of opportunity reported herein are identified, wherever possible, with flights represented by position data obtained from the Federal Aviation Agency and the Canadian Department of Transport (ranges computed from the flight strips).

For this series of reports two terms involving signal strength are used. The first of these is relative signal intensity, defined as the signal level viewed on an intensity-modulated cathode-ray-tube display, visually evaluated on a 0 to 4 scale as follows: 4, a very strong signal; 3, a strong signal; 2, a fair signal; 1, a weak signal; and 0, no signal. The second of these is effective reflecting area in square meters, defined as $\sigma = P_R(4\pi)^3R^4/P_T G^2 X^2$, where P_R is the received power in watts, P_T is the transmitted power in watts, G is the free space antenna gain, X is the wavelength in meters, and R is the range in meters. This equation is uncompensated for the degenerative influence of path loss and antenna pattern.

For the observations reported herein the Bureau of Standards propagation index was 6 ("fair to good") in the North Atlantic path. A determination of the range and range depth of the illuminated region was made at 0850 EST as shown in Fig. 1. The main transmitter pulse is blanked but considered to be positioned at zero range. The calibration signal at 600 naut mi range is 3 mv peak-to-peak and compares in amplitude with the backscatter which is considered to start at 1200 naut mi and end at 2000 naut mi. This condition was checked from time to time to verify the continued illumination of the chosen 1350 to 1800 naut mi range block. It is emphasized that the return from the backscatter area is relatively low frequency doppler clutter which is removed by Madre's comb filtering process.

Under these conditions data may be obtained from flights as much as 15 degrees in azimuth away from the beam center, and data from two or more flights at the same range

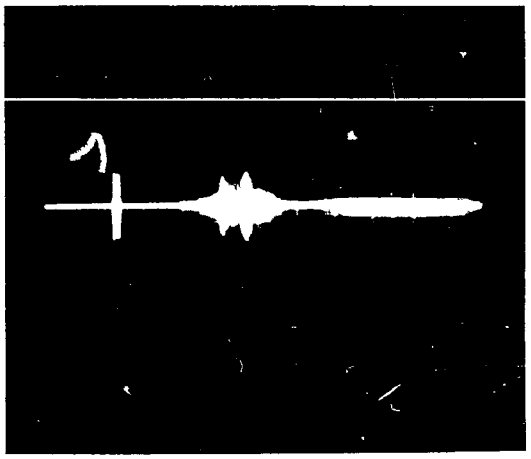

Fig. 1 - Backscatter at 0850 EST. The calibration signal at the left is 3 mv peak-to-peak and is placed at 600 naut mi range. The backscatter is from 1200 to 2000 naut mi.

can be mixed. This ambiguity is not material to a feasibility of detection study, since the antenna readily permits resolution by beam splitting if such were added. This report stresses data within ±20 degrees of beam center.

The geographical region covered includes a little section of the Santa Maria control area, for which flight strip data are not available. Within this section, there could have been intra-Azores flights, or in one small sector, flights from the Azores to the Caribbean or South America. However, the Azores to Caribbean or South America flights do not ordinarily cross this sector. Since all other flights in the observed portion of the Santa Maria control area would have reported in either previously or subsequently to the New York or Gander area, NRL feels that the available data show virtually all flights of interest. Therefore, in spite of the multiple tracking possibility, it is believed that the identifications set forth are valid.

The apparent tracks plotted from NRL's Madre data are radar slant ranges, which are readily corrected to ground range. This has not been done because the ground range calculated from the flight strip data shows a relatively fixed range offset on the plots which is a convenience in finding slopes for identification purposes.

The signal intensity vs time plots, relative and not linear in amplitude, have, here and there, certain amplitudes identified with peak signals at the receiver input.

The philosophy of identification involves conversion of the flight data to radial ranges and speeds relative to the Madre radar. Calculated flight speeds, obtained by elapsed time between successive position reports, reflect an average over a comparatively long time interval, and thus may differ considerably from the observed Madre doppler speed, which is not seriously in error. Attention is called to the fact that the speeds associated with the identified flights are bracketed by the radar speeds, some above, some below and some substantially the same.

APPARENT TRACK DATA, FEBRUARY 12, 1962

In the following apparent track plots the straight line originating at the earliest point is the predicted range versus time from this first detection and the crosses are the predicted range computed every minute until the next signal.

The first apparent track (Fig. 2a) was initiated at 1020 EST at 1725 naut mi and had a relative radial speed of 405 knots. This target was tracked to 1417 naut mi at 1102 EST. The observed radial speed varied between 394 and 423 knots. These data are initially assumed to be associated with three groups of seven aircraft: a group of three

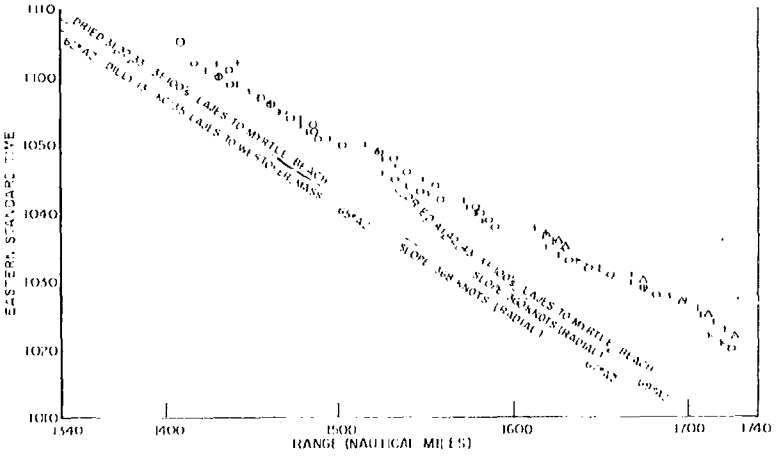

Fig. 2a - Target observed with a relative radial speed of 394 to 423 knots; antenna azimuth, 71 degrees. Note that the data points are spaced 1 minute apart. The triangles are believed to belong to the Dried 41, 42, and 43 aircraft; the circles are believed to belong to the Dilly 13 and the Dried 31, 32, and 33 aircraft.

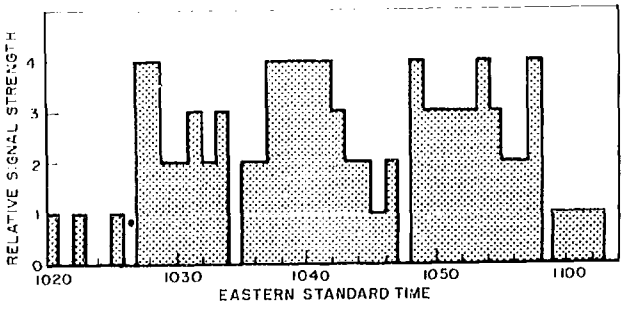

Fig. 2b - Relative (integers which are not on a linear scale) signal intensity from the aircraft of Fig. 2a. The intensities are for 1-minute periods at the time of the data points in Fig. 2a.

F-100-type aircraft called Dried 41, 42, and 43; a KC135 jet tanker called Dilly 13; and another group of F-100's called Dried 31, 32, and 33. The NRL-calculated time vs ground range plots of these aircraft groups are shown in Fig. 2a along with the apparent track. The triangles of the apparent track are believed to belong to Dried 41, 42, and 43. This formation of three aircraft registered a relative reflecting area of 1420 square meters at 1618 naut mi, a figure which is known to change considerably with time or range. The circles in the apprent track are believed associated with four aircraft, Dilly 13 and the formation flight Dried 31, 32, and 33. These craft registered an effective reflecting area of 97 square meters at 1535 naut mi. The available flight strip data converted to flight paths of these aircraft were insufficient to separate the returns into those associated with the separate aircraft. Also no attempt was made to separate the velocities using the fine velocity resolution available in the Madre secondary display system. It is noted that the converted data are between azimuths of 65 and 69 degrees, which is down on the side of the antenna pattern when boresighted at 71 degrees. A plot of the relative signal intensity versus time for the apparent track is shown in Fig. 2b.

The second apparent track (Fig. 3a) was initiated at 1017 EST at a range of 1610 naut mi and followed to 1035 EST at a range of 1468 naut mi. This track is believed to be a combination of returns from a MATS KC135 jet tanker called Dilly 12 and flight QF501, a Boeing 707 flying from London to New York. From the slopes of the time vs range plots of these flights and the radar track the circles in the latter are associated with Dilly 12 and the triangles to QF501. The radar-observed radial speed varied between 422 and 437 knots. Note that the NRL's converted radial speeds for these craft fall below and above the observed radial speeds. The signal intensity vs time plot of the apparent track is Fig. 3b. The break in the base line at 1019 EST was due to equipment problems; the others are due to the observer's absence. (Note that a value 0 for "no signal" is indicated by a plot slightly above the 0 ordinate in order to form the base line.)

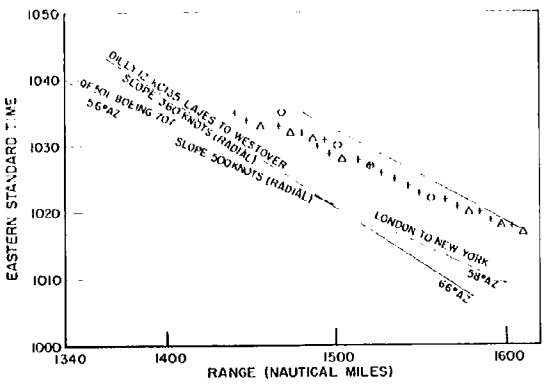

Fig. 3a - Target observed with a relative radial speed of 422 to 437 knots; antenna azimuth, 71 degrees

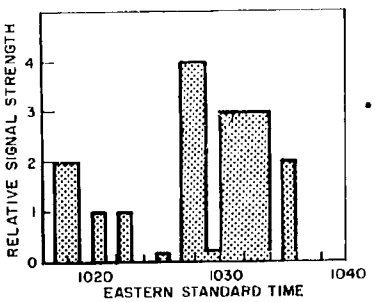

Fig. 3b - Relative signal intensity from the aircraft of Fig. 3a

The third apparent track (Fig. 4a) was initiated at 1033 EST at a range of 1763 naut mi and terminated at 1103 EST at a range of 1476 naut mi. This track is believed to be identified as TWA flight 8380, a Boeing 707 flying from Paris to New York. This plane registered an effective reflecting area of 326 square meters at 1695 naut mi. There is a 47-mile deviation (3% range error) from the final position predicted from the first

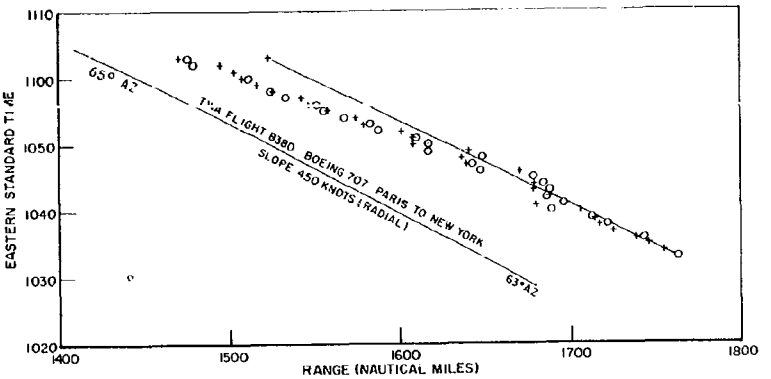

Fig. 4a - Target observed with a relative radial speed of 477 to 480 knots; antenna azimuth, 71 degrees

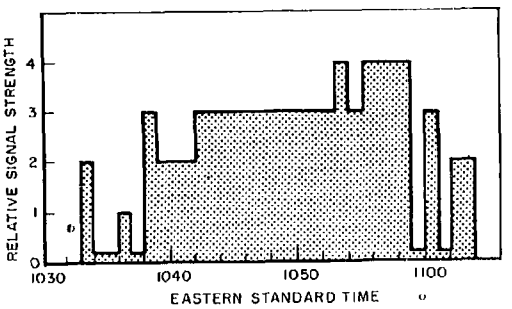

Fig. 4b - Relative signal intensity from the aircraft of Fig. 4a

observation and the final observation. The relative signal intensity vs time plot (Fig. 4b) shows a high signal level for most of this flight even though the detection was made at an azimuth of 62 degrees, 9 degrees from boresight.

There were other aircraft (Pan American flight 73 and a group of F-100's) in the vicinity that match the range readings for this apparent track. However, they matched only portions of the track and were even farther away from the beam center. Therefore, preference was given to TWA flight 8380 as being the most probable aircraft to generate the entire track.

The fourth apparent track (Fig. 5a) was initiated at 1037 EST at a range of 1773 naut mi and a speed of 413 knots. It was terminated at 1462 naut mi at 1114 EST (disregarding the points at 1117 and 1118 EST). The observed radial speed varied from 413 to 452 knots. This track has been identified with returns from Dilly 14, a KC135 jet tanker enroute from Lajes, Azores, to Westover, Mass. (CEF). The plots in Fig. 5a indicate a target bearing between 67 and 65 degrees azimuth, while the antenna beam center was at 71 degrees azimuth. At the power used, the beam width of the antenna will accept targets this far off the beam center, as evident from the data for the track in Fig. 4a. The relative signal intensity vs time plot (Fig. 5b) shows a decreasing relative signal intensity with increasing azimuth displacement from the beam center, even though range is decreasing.

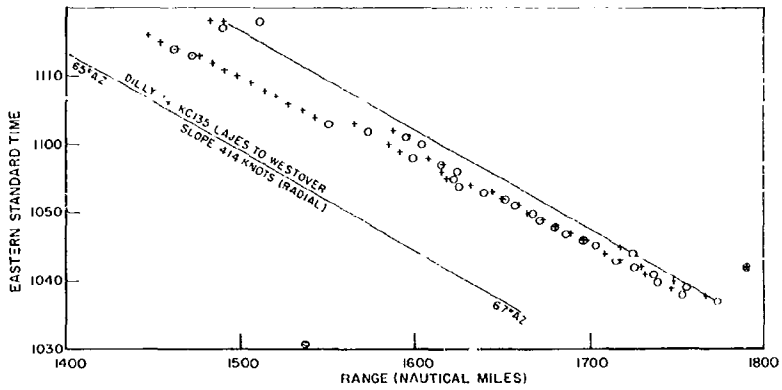

Fig. 5a - Target observed with a relative radial speed of 413 to 452 knots; antenna azimuth, 71 degrees

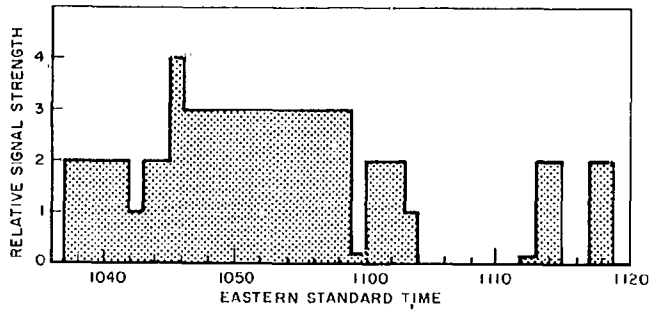

Fig. 5b - Relative signal intensity from the aircraft of Fig. 5a

The fifth apparent track (Fig. 6a) was initiated at 1043 EST at a range of 1783 naut mi and terminated at 1118 EST at a range of 1472 naut mi. As shown from the plots of flight data, there are two aircraft that must be considered. One MATS Dilly 15, a KC135 tanker enroute from Lajes, Azores, to Westover and Air France flight 001, a Boeing 707 enroute from Paris to Montreal. Since Dilly 15 was from 68 to 64 degrees azimuth and Air France 001 was from 63 to 56 degrees azimuth, it is believed that Dilly 15 is the more probable aircraft. This aircraft registered an effective reflecting area of 88 square meters at 1729 naut mi. The relative signal intensity vs time plot for this apparent track is Fig. 6b. The observed and calculated radial speeds are noted (Fig. 6a) to be comparable.

The sixth apparent track (Fig. 7a) was originated at 1052 EST at a range of 1795 naut mi and continued until 1129 EST at 1512 naut mi range. The time vs range plot of this track shows severe spreading, implying multiple target contribution. The observed velocity spread reinforces this implication. The data from the New York control center yield only one flight, Swissair flight 816, a DC-8 enroute from Lisbon to New York, as a reasonable source aircraft. Since the earliest position report on this flight was at 1130 EST, the positions shown are extrapolated and may be slightly less accurate than for other

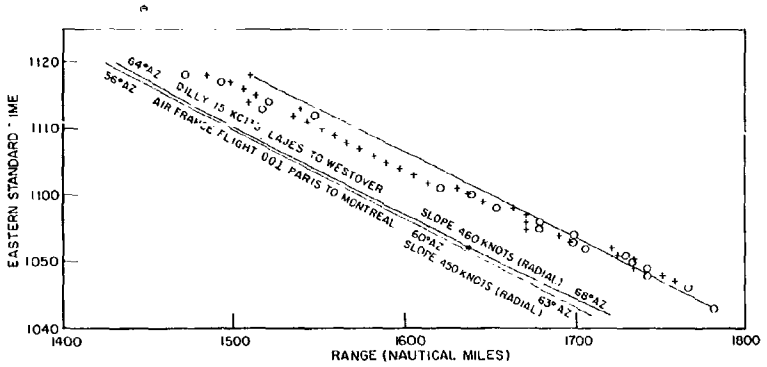

Fig. 6a - Target observed with a relative radial speed of 467 knots; antenna azimuth, 71 degrees

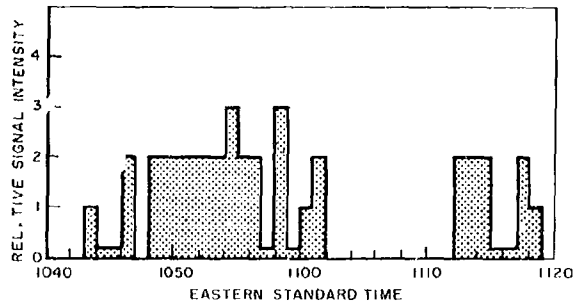

Fig. 6b - Relative signal intensity from the aircraft of Fig. 6a

flights identified. Gander data indicate the presence of a MATS flight Dried 51, which is suspected to be a group flight covered by the single designation, listed as an F-100 enroute from Lajes to Myrtle Beach. Both of these flights are nearer to beam center at the start of the track than at its termination, a condition reflected in the decreasing signal intensity vs time record (Fig. 7b). The average radial speeds of 385 and 458 knots agree quite well with the observed speeds, which lie between 394 and 450 knots.

The seventh apparent track (Fig. 8a) was initiated at 1112 EST at a range of 1742 naut mi and terminated at 1145 EST at a range of 1458 naut mi. This track has been identified with Air France flight 707, a Boeing 707 enroute from Paris to New York. The time vs range plot of this aircraft and the radar data show a rather smooth track with 28 miles difference between the predicted range from the first detection and the last observation. Note also that the observed and calculated average radial speeds agree quite well. The relative signal intensity vs time plot for this aircraft is Fig. 8b.

The eighth apparent track (Fig. 9a) was initiated at 1126 EST at a range of 1694 naut mi. These track data are identified with two aircraft flights, the time vs range plots of which are shown in Fig. 9a along with the apparent track. The triangles are believed to be associated with Dried 61, 62, and 63, a flight of three F-100's, and the circles with the Dilly 16, a KC135 jet tanker. The relative signal intensity vs time plot is Fig. 9b.

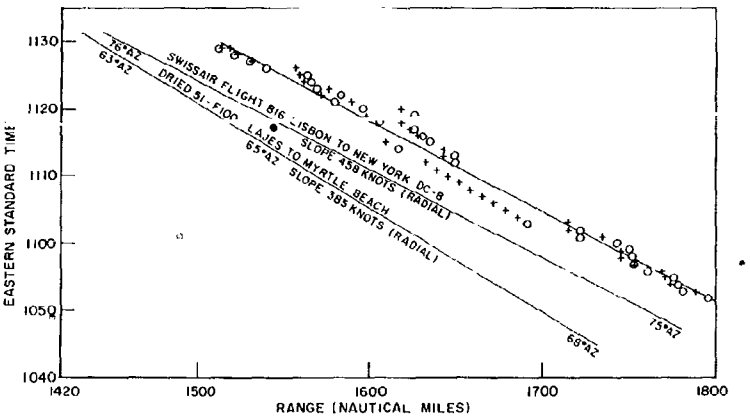

Fig. 7a - Target observed with a relative radial speed of 394 to 450 knots; antenna azimuth, 71 degrees

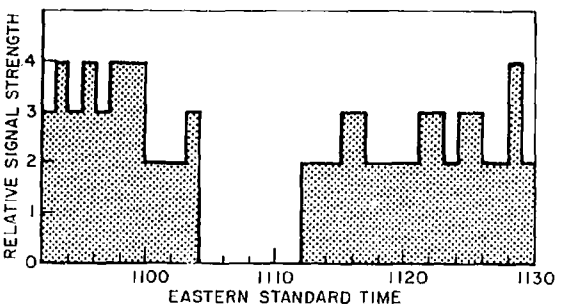

Fig. 7b - Relative signal intensity from the aircraft of Fig. 7a

The ninth apparent track (Fig. 10a) was initiated at 1337 EST at a range of 1763 naut mi and terminated at 1413 EST at a range of 1464 naut mi. The track has been identified as flight 005JA, a Boeing 707 enroute from London to New York. The average calculated speed of this flight is bracketed in the range of the observed radial speeds. Figure 10b is the relative signal strength vs time plot of this aircraft.

The tenth apparent track (Fig. 11a) was originated at 1356 EST at a range of 1706 naut mi and terminated at 1404 EST at a range of 1645 naut mi. The converted flight strip data show two aircraft that must be considered to identify the apparent track: one, Pan American flight 1, a Boeing 707 enroute from London to New York at 58 degrees azimuth, the other, TWA flight 701, a Boeing 707 enroute from London to New York at 60 degrees azimuth. With two aircraft at reasonable range, three possibilities exist for this apparent track: all signals from the Pan American flight, all signals from the TWA flight, or a combination of signals from both. Range correspondence is equally good for the second and third of these possibilities, somewhat less good for the first. The smoothness of the apparent track lends weight to the second possibility over the third. In addition, the curvature of the path of TWA flight 701 implies decreasing velocities radial to Madrc, in agreement with the radar track, while data from PA1 should show increasing

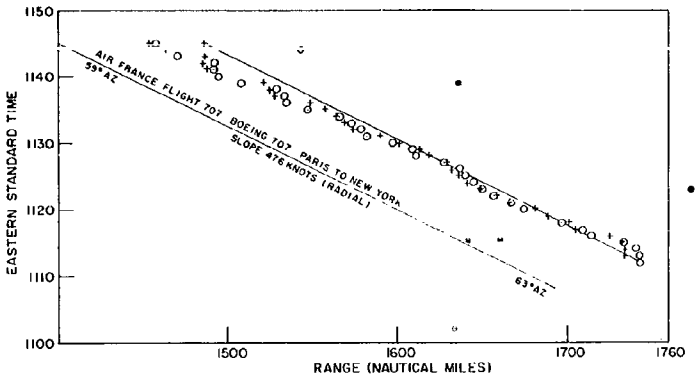

Fig. 8a - Target observed with a relative radial speed of 466 knots; antenna azimuth, 71 degrees

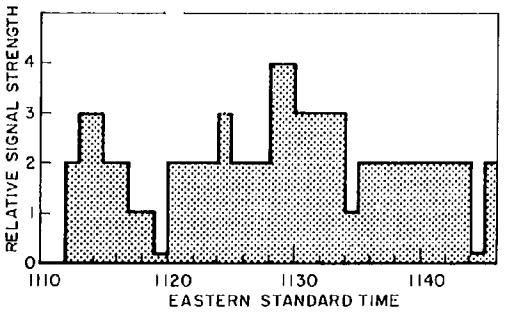

Fig. 8b - Relative signal intensity from the aircraft of Fig. 8a

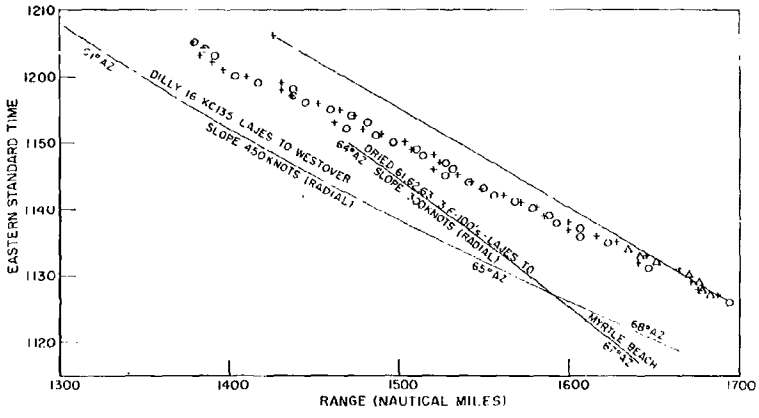

Fig. 9a - Target observed with a relative radial speed of 402 to 418 knots; antenna azimuth, 71 degrees

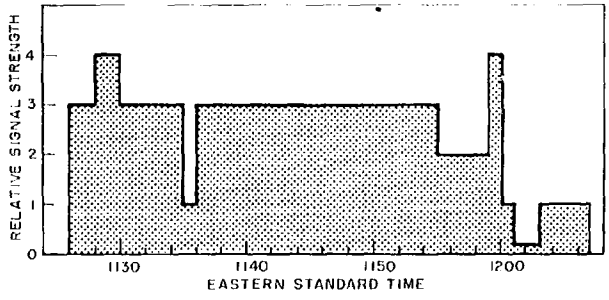

Fig. 9b - Relative signal intensity from the aircraft of Fig. 9a

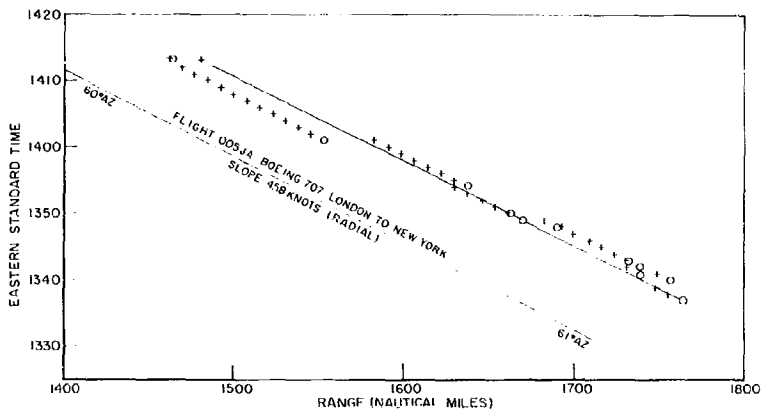

Fig. 10a - Target observed with a relative radial speed of 425 to 472 knots; antenna azimuth, 71 degrees

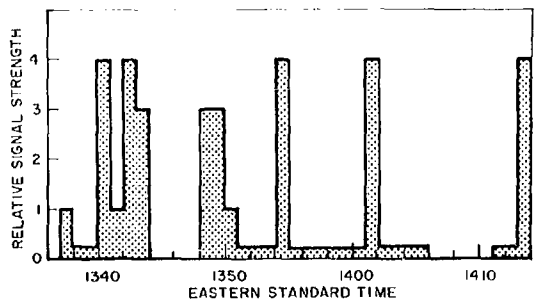

Fig. 10b - Relative signal intensity from the aircraft of Fig. 10a

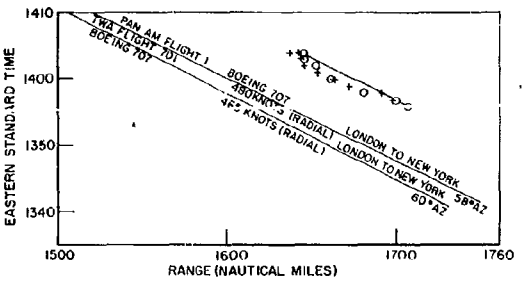

Fig. 11a - Target observed with a relative radial speed of 472 to 483 knots; antenna azimuth, 71 degrees

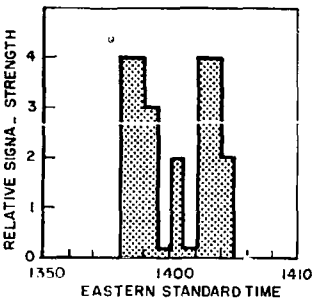

Fig. 11b - Relative signal intensity from the aircraft of Fig. 11a

velocities. Therefore, in spite of a slight azimuth preference for Pan American flight 1, the track is identified as TWA flight 701. The relative signal intensity vs time plot for this track is Fig. 11b.

CONCLUDING REMARKS

Consideration of the identification problems with multiple aircraft shows that a finer azimuth discrimination would help eliminate some of the multiple aircraft confusion and make identification more positive. This refinement could be installed in the present equipment but is not being considered at this time because it is not believed necessary in the evaluation of the capabilities of an ionospheric radar.

Better navigational data from the aircraft would aid in identifying the aircraft generating the return. This has been demonstrated on controlled flights where the navigator used all the aids at his command to give the best positions possible. Some of these will be discussed in further reports in this series.

Work is continuing in evaluating the performance of the Madre radar against aircraft and missiles.

ACKNOWLEDGMENT

The authors acknowledge the efforts of the personnel who observe the data and keep the equipment in operable condition. In this report the excellent work of the Section Heads Messrs. F.E. Boyd, J.M. Headrick, and G.K. Jensen is specifically acknowledged. In addition the work of Mrs. M.E. Thorpe, Messrs. S.R. Curley, J.L. Ahearn, W.B. Patton, M.S. Lieberman, D.C. Rohlfs, E.W. Ward, and F.E. Wyman is commended. Madre is a jointly supported program funded by the Air Force, ARPA, and the Navy.

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